A MULTILEVEL AND MULTI-SCALE METHOD TO OPTIMISE THE SUSTAINABLE CONSTRUCTION WORKS

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Abstract. *The nature of the sustainable approach in the construction management is complex, because of large number of involved components and relationships between disciplines, objects, phases of the life cycle, aspects and variables of any actual project or construction works process. Complexity is one of the major assumptions of the conceptual model on which the new, still in progress, European assessment standard family of CEN TC 350 is based, adopting a multidisciplinary approach. However, the future developments are expected to go more and more into the direction of the integration of the three major components in the life cycle: environmental, social, economic, as well as at the international level the discussion on wider system boundaries, beyond the building, is going on. These are sufficient grounds to start managing any case of construction works as an interdisciplinary and multi-layer issue, evaluating and planning any action as the integration of a certain number of actions involving many variables and producing cross effects. At this point a multiscale and multilevel approach becomes indispensable. The paper actually contributes to start up a new generation of sustainable approaches at construction problems, reporting on the research focused on the development of inductive, logical/operational guidelines, aiming at optimising the sustainable management of construction works. The identification of a multiscale and multilevel method supporting the decision-making process, focused on key objectives/ criteria/ indicators with respect to the energy, environmental, social and economic performances, is applied to "Città Studi Campus Sostenibile". The project, member of the ISCN network and inserted in the European Peripheria framework, is promoted by the Politecnico and the University of Milan to transform the university district into a model part of the city in terms of quality of life and environmental sustainability.*

Keywords: *sustainable construction works, European standards, Multilevel, Multi-scale, Integrated approach*

1 INTRODUCTION

After years of development and application of methods for *assessing* the sustainability of buildings in various parts of the world, and the related "labeling" of the buildings, the European Union has felt the need to adopt an "umbrella" policy, developing and sharing common framework methodologies and indicators between the Member States. The Standards, set out by CEN TC 350 "Sustainability of construction works", are supposed to be voluntary and are still under development, also considered the huge need of time required by a similar route, including the exchange of proposals and approvals of complex documents at both central and peripheral / national working groups and levels of the European Union (Ilomäki et al. 2008).

In the meantime all the Standards are going to be adopted, it is necessary that a *virtuous process of implementation and monitoring* applied to real cases starts, so to *test the effectiveness* of the available *standards*, and identifying the gaps in the perspective of the future revisions of the first standards to be published. The research presented is still in progress, aiming to provide a contribution in this direction.

Actually, in the real cases of application, *the traditional tools and strategies* of project management show their own *limits* when the decision-maker seeks sustainable goals.

The paper aims at giving a contribution to fill this gap, paving the way to develop *appropriate methods / guidelines* for the management of sustainability in constructions, in order to *support a decision-making process* (by public and private managers, planners, developers, policy makers) from a *sustainable point of view*.

The main goal is the identification of a *multi-scale* operative method applied to the different phases of the construction process, aimed at improving energy (Masera 2004) (Palazzo et al. 2011), environmental and social performances, with respect to the building, the urban and the neighborhood context, helped by the setting of *key indicators* (environmental, economic, social).

2 CONTEXT

2.1 State of art

With no doubts one of the major merits of the *environmental labels and rating systems* for the *assessment of sustainability in construction works* is the start of a widespread process of awareness about the importance of the resource use and related limits.

On the other hand, it is widely recognized by the international community not only the researchers but also the operators of the construction supply chain that the worldwide proliferation in recent years has also produced several problems, first of all a sense of disorientation by the stakeholders (designers, contractors, public authorities).

The diffused application of the different rating systems has also showed, in addition to the difficult manageability of an even large number of indicators, the limits of such assessment methodologies with respect to aspects and impacts not expressly quantifiable.

2.2 Developments

For the above reasons, the European scientific community, under the pressure of the European Commission, is involved in several research programs supporting the harmonization process of the existing standards (Ilomäki et al. 2008), in particular attempting to:

- The definition of a *single tool* to assess the sustainability (and improve performance) (Gargiulo 2012) for all stages of the process, including CED (Cumulative Energy Demand), LCA (Life Cycle Assessment) of products and processes with reliability of performance and assumed actual measured values TQA (Total Quality Assessment), LCC (Life Cycle Cost) for the evaluation of economic indicators such as economic risk investments, profitability, etc. (Daniotti et al. 2010).
- The *simplification*, drastic reduction in the number and in the application of indicators

- The transition from a *first generation of indicators* (only environmental pressure-state-impact) to a *second* one (environmental, economic, social), easier to use.

The method adopted by CEN TC 350 for managing the sustainability of buildings is essentially based on the following categories subject to analysis and evaluation: *Aspects, Impacts, Performances, Indicators*. Each category is applied to each *stage* of the building *life cycle* (Daniotti 2012) and is so defined:

- *Aspect:* aspect of the construction of an assembly (of the building), processes or services related to their life cycle (Lavagna 2008) that can cause changes in environmental, social/ quality of life, economy;
- *Impact*: any change to the environment, society/ quality of life, economy (the users of the building, or the owner, operator and occupants, and neighbors), positive or negative, in whole or in part resulting from environmental/ social/ economic;
- *Performance*: relative performance (Gargiulo 2008) impacts and environmental aspects/ social/ economic (Stoy et al. 2011).

The suggested methodology of performance evaluation will take into account aspects and impacts / performances that can be expressed in *quantitative indicators*, measured without value judgments.

2.3 Conceptual framework

A method of managing complexity, especially taking into account sustainability, needs to be planned and developed using logic and graphic techniques and tools that bring together different and interacting categories (variables), taking care to search for cause-effect linkages, convergences, divergences, and any reasonable relationship between one and the others.

Even the methods that CEN TC / 350 is developing to manage the environmental/ social/ economic interactions between the *internal and external variables*, playing in the construction process along the whole life cycle, are based on this assumption.

Actually, the common introduction to the European standards reports: "In the future, the assessment methodologies within this standard framework may be part of an overall assessment of *integrated building performance*. The assessment methodologies may also be extended to an assessment of the neighborhoods and wider built environment".

And yet, in the definitions, sustainability assessment of buildings is described as a "*combination of the assessments of environmental performance, social performance and economic performance* taking into account the technical requirements and functional requirements of a building or an assembled system (part of works), expressed at the building level".

In other words, since the first draft writing, was already covered that future reviews will be set in a perspective, but also practically organized, based, not just on the analysis and assessment of the variables taking place, but on the integration of three (environmental / social / economic) components. And it means that *as much as we are able to manage integration as an aspect of complexity, the more we will be successful to achieve the sustainability goals*.

3 METHODOLOGY

3.1 Case study

"Città Studi Campus Sostenibile" is an international multi / inter - disciplinary project, focused on the energy / environmental / social up-grading of the Italian University Campus Leonardo (Politecnico di Milano and Università degli Studi di Milano) and its neighborhood (www.campus-sostenibile.polimi.it) (Bruglieri et al. 2011).

The Politecnico di Milano plays a significant international role in the field of engineering and technology as well as in architecture and design. Established in 1863, the school moved to the current site of Città Studi in 1927. Buildings are owned, managed and maintained by the institution. The campus is composed of old buildings (most of them are from the 20ies of the last century, some of the 60ies and only few were constructed in recent years). Some buildings represent significant samples of the Italian modern architecture, designed by well-known architects. The sustainable campus project concerns the “Leonardo Campus”, which is the main one of the seven campus of Politecnico di Milano distributed around the Lombardia region. Today, the “Leonardo Campus” occupies a surface of 186.613 m^2 and 17.484 students are enrolled in the different programs. In addition, 1.748 staff members (professors and personnel) work every day on the campus.

The first challenge is a strong commitment to reduce the energy consumption of buildings. The initial stage of the work, conducted in 2007, was mostly dedicated to create a baseline for measurements and the quantification of indicators, describing main characteristics (orientation, lighting layout and activation, heating and cooling devices, windows, shading devices, etc.) of the 3.700 building spaces and more than 100 fields for each zone. At the current and the further stages the aim is creating a *virtuous system of management*, related to the maintenance work plan and potentially redirecting and improving design choices. This strategy is expected to ensure at present and in the future the valuing and integration of new sustainable projects and initiatives at the *building and campus levels and connected with the urban context*.

3.2 Reference models

The International Council on *Systems Engineering* (INCOSE) defines systems engineering as "an *interdisciplinary approach* and *method to enable the realization of successful systems*. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with the design of architecture and system validation, always taking into account the totality of the problem. The discipline of Systems Engineering integrates all the disciplines and specialties of various working groups forming a *structured development process that proceeds from concept to realization and commissioning of the system*. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets *the needs of users*".

Another factor is related to the ability to identify and manage the *network of relationships, dependencies and dynamics between different components of a complex system*. The goal is to "guide them" into an overall behavior resulting from the *harmonization* of those parts, it would not be possible to obtain simply by putting them together. The skill lies in being able to predict the interactions between the different elements that contribute to the overall behavior and control them.

To avoid overlooking relevant aspects of the problem, or to minimize this risk, the system administrator typically adopts a "*top-down*" and proceed in a structured manner, often repeatedly *through the different levels and different dimensions in which the problem can be splitted*.

3.3 Method and application to the case study

The conceptual model elaborated in the research is *multidimensional*, because, as anticipated, there are many variables involved. The *critical issues* are highlighted by the intersections between the different set of variables involved in the case study.
In synthesis, the *method and supporting models* are featured as:

- *Multi-dimensional,*
- *Multi-criteria,*
- *Multi-layer*.

The aim is visualizing the complexity, reducing the initial model in simple partial models and therefore manageable, then recomposing the results in order to find the output corresponding to the given input, as reported in the logic chain: *Complex Input - Simple Issues - Recomposition - Interpretation / Correction – Output.*

In order to better manage the *multi-criteria* analysis, in line with modern theories and techniques of statistics, economics, and engineering involved in decision-making, the under development method is based mainly on the use of *matrices*, crossing one by one criteria and alternatives or set of variables to each other, and *multi-layer* tools, linking more than one set of variables to each other simultaneously. The aim is to obtain, crossing logically variables between them, much information as possible about the different *combinations*, to discover the *effects of possible actions* with a view of *integration* and *synergy*. The target of the analytical work in support of the decision-maker is to identify a panel of indicators suitable for subsequent stages of decision-making processes, to submit to the stakeholder groups. The following set of variables (and related *key factors*) have been identified as characterizing the different attributes of the case study:

• *Multi-role (A)*	Responsibility
• *Multiactivity (multi-function) (B)*	Functional requirements
• *Multi-scale (C)*	Spatial interconnections
• *Multi-sector (D)*	Integration with the city
• *Multi-objective (E)*	Decisional roles
• *Multi-stage (F)*	Life Cycle
• *Multi-stakeholder / multi-interest (G)*	Corporate Responsibility
• *Multi-impact (H)*	Cause-effect relationships
• *Multi-performance (I)*	Efficiency
• *Multi-indicator (L)*	Evaluation.

For each one of the above sets are identified a certain number the actual *variables* and the profile as involved in the project. By way of example, following are presented the profiles of the Multi-impact (H) and the Multi-performance (I) sets of variables.

- *Multi-impact (H) profile*:

Each action by the D.M. (Decision-Maker) determines such impacts. With a view to sustainable development, the impacts are broadly grouped into three categories:

- environmental
- social
- economic.

Actually, any action, such as deciding whether to use a particular component / product / material in a building or to build using a given structural material (eg wood, or reinforced concrete) causes an impact or generates a number of impacts that may also not be inscribed in one of three main categories. For example, a certain material, permanently inlaid in a room, eg. a classroom, produces a measurable impact on the environment in CO2 equiv., but it is also due to effects on the health of the occupants. Therefore, it impacts on the environment and society. And if the same material is put in place in an office room, it generates a third impact: economic, since the effect on the health of the employee is reflected in his work productivity.

Taking as reference the relevant indicators, as identified by CEN / TC 350 and in related European projects (SuPerBuildings, Open-House), the impacts can be substantially the following way.

Direct:

- environment (land use, water, energy, resources, placing of waste)
- on the health of the occupants

Indirect:

- fallout on the global environment and ecosystems at different scales (photochemical pollution, global warming, carbon footprint, etc.)
- level of user satisfaction and consequent productivity / social diseases, etc. (society - economy)
  effects on the quality of life of external social groups (eg residents of adjacent neighborhoods)
- effects on the macro economy (employment in industry and manufacturing, purchasing raw materials, contribution to recycling, imports, etc)
- effects on the micro economy (LCC, in particular energy consumption during the various stages and especially that of use) (Stoy et al. 2011)
- reflections on the local economy (value or devaluation of the site).

The impact on the outside, the so-called “externalities”, especially in a context such as the particularly dense urban environment, are too often neglected in practice, more or less consciously by decision-makers, and difficult to control in a step subsequent to that decision. As we know, too much often, they might end up to fall in the sphere of health and well-being (environmental and social), and a little later also economical for the high costs associated with health.

- *Multi-indicator (I) profile*:

If performances are normally in relation to the impacts (negative effects), the other category of the results of actions and therefore the choices (technical solutions, design, use of materials and components) to be taken into account in an assessment of the sustainability of a intervention, in certain contexts, such as structures of excellence, are a key factor.

This is due to their direct reflection on the "total quality" of the object of evaluation, as well as to a number of indirect effects on the user. The performance is expressed by the indicator, which measures the "behavior", that translates into how far away the object number of performance-evaluation with respect to a reference value (benchmark). Obviously the goal is to minimize or maximize the impact and effect depending on the specific case where the impact is positive or negative, so that the construction / operation will respond in the best way possible with the established requirements (functional / technical, environmental, economic, social / cultural).

The expected performances in the case study concern to:

- the Reputation of the University (parameters used in the common methodologies for evaluating the level of quality of the University - international benchmarking)
- the Reputation of the Stakeholders (good performances can be certified as much qualified are the construction actors, eg. investors, designers, contractors, suppliers, etc.)
- the Environment (efficiency of design and technical solutions for saving water, energy, resources and waste minimization)
- the Users (level of functionality: accessibility, space and functional efficiency)
- the Owner / the tenant (fexibility, adaptability).

The second step of the method development has been the creation of a navigational matrix ("framework", Figure 1), which identifies the objective relations (constraints in either direction, interferences) with a view of sustainability, in particular related to the construction process / transformation of the city, present / not present between the set of variables, taken two by two. They also indicate the "relevant aspects" of these reports, to focus the thematic areas of *sensitive relationships* to have an overall idea of the problems and areas where the search for solutions. But they can also be considered as the *strategic aspects* on which to intervene on the basis of *environmental / social / economic criteria*, activating solutions today considered *sustainable*.

Below is the *Legend of Figure 1:*

■ existence of relevant relationships

□ absence of relevant relationships / existence of not relevant relationships

R - real estate

P - public procurement

A - environmental (impacts, performances)

S - social (impacts, performances)

E - economic (impacts, performances)

Variables Set / Variables Set	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**L**
A – Multi-role	-	■	■	■	■	■	■	■	■	□
		R/ S/ E	A / S / E	R / P / A / S	P / R	P / R / S / E	S	A / S / E	R / A / S / E	
B - Multiactivity (multi-function)	■	-	■	□	■	■	■	■	■	■
	R/ S/ E		S		P / R / A / S / E	R / A / S / E	S	A / S	S / E	S / E
C - Multi-scale	■	■	-	■	■	■	■	■	■	■
	A / S / E	S		A / S / E	A / S / E	A / S / E	A / S / E	A / S / E	A / S / E	A / S / E
D - Multi-sector	■	□	■	-	■	□	■	■	■	□
	R / P / A / S		A / S / E		P / A / S / E		R / A / S / E	A / S / E	R / A / S / E	
E - Multi-objective		■	■	■	-	□	■	□	□	■
		P / R / A / S / E	A / S / E	P / A / S / E			R / S			P / R
F - Multi-stage	■	■	■	□	□	-	■	■	■	■
	P / R / S / E	R / A / S / E	A / S / E				P / R / S	P / R / A / S / E	A / S / E	A / S / E
G - Multi-stakeholder / multi-interest	■	■	■	■	■	■	-	■	■	■
	S	S	A / S / E	R / A / S / E	R / S	P / R / S		R / S	A / S / E	P / R / A / S / E
H - Multi-impact	■	■	■	■	□	■	■	-	■	■
	A / S / E	A / S / E	A / S / E	A / S / E		P / R / A / S / E	R / S		A / S / E	A / S / E
I - Multi-performance	■	■	■	■	□	■	■	■	-	■
	R / A / S / E	A / S / E	A / S / E	R / A / S / E		A / S / E	A / S / E	A / S / E		A / S / E
L - Multi-indicator	□	■	■	□	■	■	■	■	■	-
		A / S / E	A / S / E		P / R	A / S / E	P / R / A / S / E	A / S / E	A / S / E	

Figure 1: The navigational matrix to manage the complexity of the relationships between the sets of variables involved, highlighting the crucial issues

4 RESULTS AND DISCUSSION

Observing the navigational matrix (Figure 1), some early considerations can be done. The *social aspects* are very present both at the levels linked to a geographic / spatial / function (together with those related to the building project management), as well as to those more closely related to the themes "green" (sustainable development). They can therefore be considered "cross" to all the sets and substantially on 3 areas:

- territory / population
- building
- social groups (stakeholders).

They can also be divided in social aspects:

- relating to the *physical* characteristics (accessibility of the site and building, technical accidents on health and welfare, etc.)
- relating to the *sociological* sphere (consequences of behavior, relationships among stakeholders, etc.)

Because of their sheer number, heterogeneity and often difficult to focus, however, as deemed by the scientific community that is helping with the most advanced studies in European standardization work, their development certainly deserve a lot of effort and attention. From this point of view, also the DM (decision-maker) covered with a "social responsibility", an obligation which requires him to include actors and social groups (stakeholders) affected by its choices in the decision-making process both as the advisory and proponent actors.

The *environmental* aspects (use of resources and energy, emissions and waste), properly studied in the context of ecology or starting point of the work of setting standards CEN TC 350, are *transverse to the scales* and abide by the direct responsibility of the DM and those who work with him in the process of implementation of the decisions as in the building.

These must bear in mind that the setting of each goal among the possible alternatives (build a new building rather than rent or renovate another, for example) inevitably generates effects (impacts) on the shared environment. The involvement on the part of D.M. stakeholders in the choices means not only have a voice to protect the interests of the represented part, but, as is clear in this case, to become co-responsible, as in the positive so in the negative reversible / not reversible impacts due to the choices on the environment.

The *economic* aspects have the characteristic of being present in many areas and relationships, and of being different depending on the scale. They range from those related to micro-economics and real estate procurement (more easily controlled and controllable) to the macro-economic effects of the choices that the DM does within a plurality of variables most elusive in its control and very even to his knowledge. The latter are only partly controllable and require extensive knowledge of the subject. Social responsibility in this area is actually a field rather "mined" for the DM. The close connection with the cycle of life, both at the macro level (involving different spatial scales) and micro (building or part of it, the whole Campus) requires the DM to consider all items of LCC (Life Cycle Cost) and examine their correlations with all possible aspects. Ensure that the LCC, which is actually a methodology widely known and applied, becomes in effect a strategic support for decision-making.

5 CONCLUSIONS

The research is still under development. However, some early conclusions from the first step and related application of the method have been drawn and are below reported:

1. The decision-making process in construction works belongs in itself to the *general area of complexity*.
2. Sustainability is a wide concept and even *dividing the aspects, performances and impacts of any process by components* (environmental, social, economic), this is only a start point, because of the *high level of the variables and the relationships* engaged.
3. Disciplines and andvanced knowledge areas as i.e. SE (Systems Engineering) or MCDM (Multicriteria models and methods for decision-making) are able to offer models and methods to help the management supporting the decision-making.
4. Any multi-dimensional/criteria problem in construction works can be managed using a *Top-down and Multilevel approach*, dividing the complex input into simple parts, described by *sets of variables* and analysing the relationships between the sets.
5. The identification of mentioned sets of variables involved in the problem and the *visualization* by matrices can be useful to the project manager and the decision-maker to detect the relationships and chains of causes-effects taken in by any option of choice, to *identify, keep under control* along the whole decision-making process and hereafter *monitor* during the *life cycle, the crucial issues*.
6. Further developments in this field are expected, in order to offer to the construction actors, particularly managers and decision-makers, *appropriate methods / guidelines* for the *optimization* of construction works from a sustainable *point of view*.

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